500-kW Thorium Target for Concept

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Project X Physics Study

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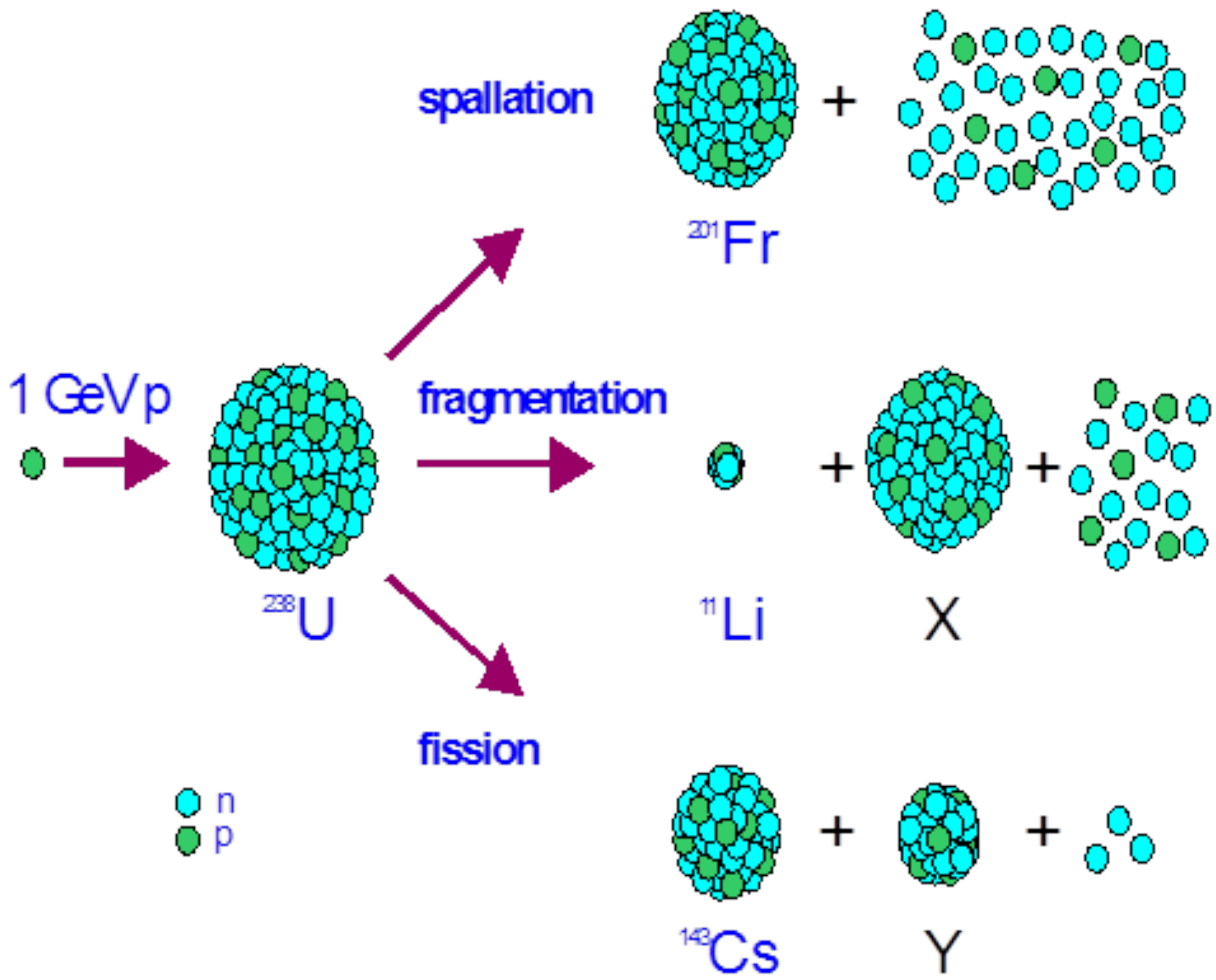
Outline

- Typical ISOL proton spallation target/ion sources (CERN/ ISOLDE)
- TRIUMF ISAC target/ion sources, 500 MeV p, 100 microamps
- INFN Legnaro SPES facility UC2 target design, 40 MeV p, 200 microamps; tests at Oak Ridge HRIBF
- 500-kW thorium target concept for Project X: Rn, Fr, Ra isotopes (500 microamps)
- Monte Carlo simulations of effusion from target chamber

Reaction mechanisms



Project X: Target Spallation Production

Protons on thorium target: 1 mA x 1000 MeV = 1 MW

Predicted yields of some important isotopes:

Radon: $^{211}Rn > 10^{13}$ $^{219}Rn \sim 10^{14}$ /s $^{223}Rn \sim 10^{11}$ /s

Francium: $^{213}Fr > 10^{13}$ $^{221}Fr > 10^{14}$ $^{223}Fr > 10^{12}$ /s

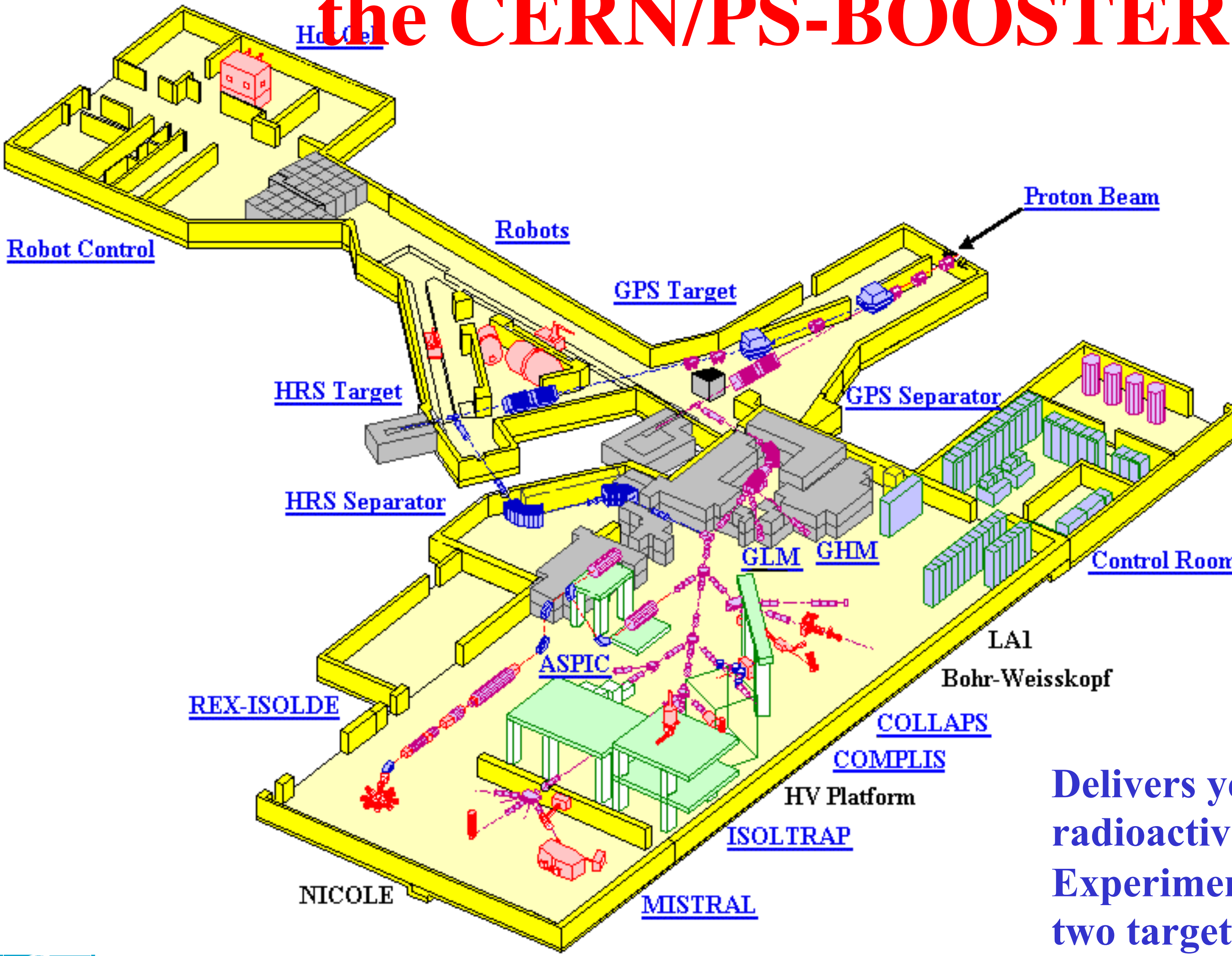
Radium: $^{223}Ra > 10^{13}$ $^{225}Ra > 10^{13}$ /s

Actinium: $^{225-229}Ac > 10^{14}$ /s

Yields simulated by I.C. Gomes using MCNPX, Project X workshop, October 2009

Project X will enable a new generation of symmetry-test experiments, and bring exciting opportunities for discovering physics beyond the Standard Model.

The Isotope Separator On-Line ISOLDE at the CERN/PS-BOOSTER



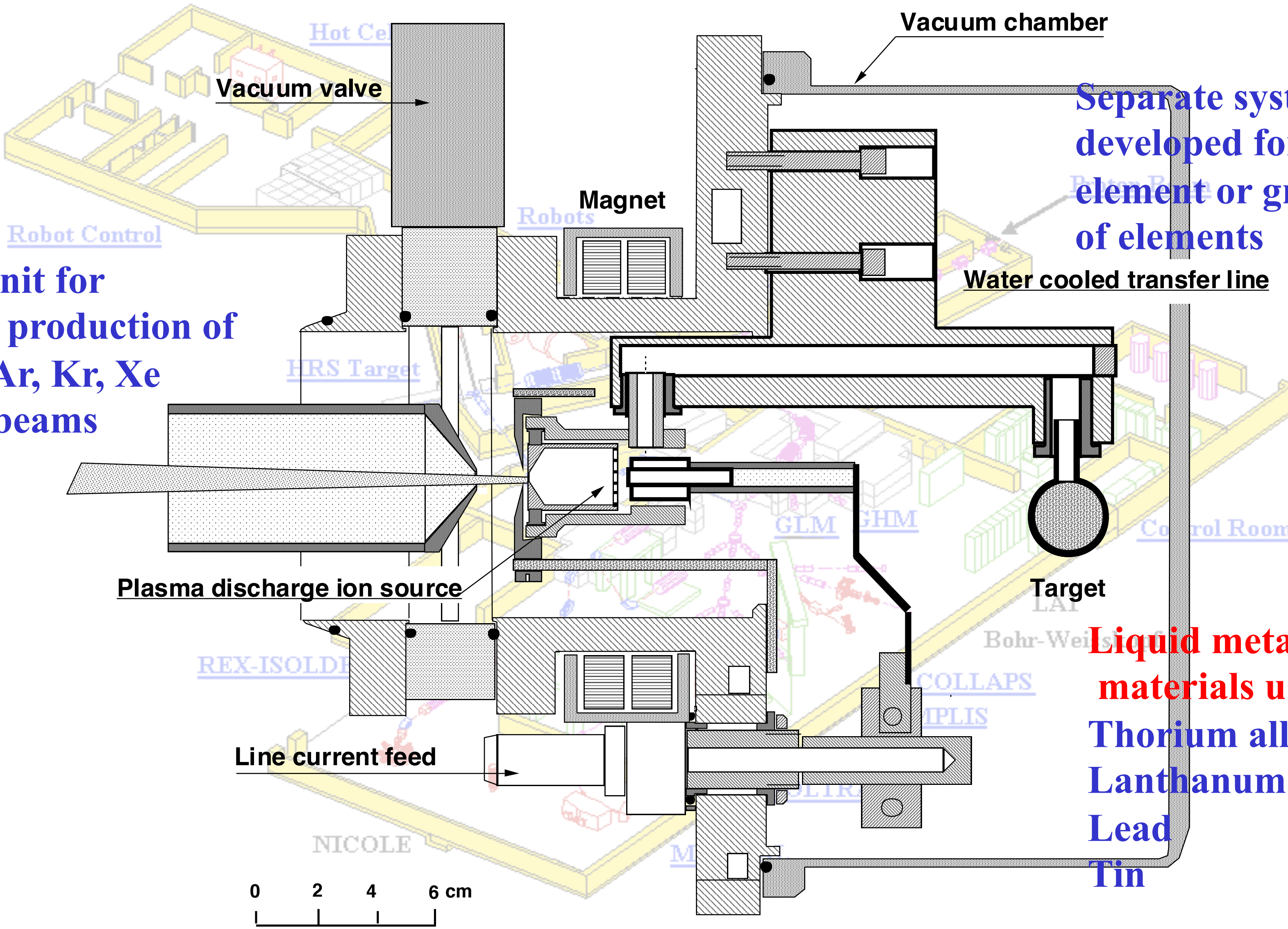
Proton beam:

1 -1.4 GeV
3E13 per pulse
2.4 μs pulse length
Rep. Rate 0.5 Hz
Max. current 4 μA
5.6 kW beam power

Delivers yearly 3200 h of radioactive ion-beam to 30 Experiments by means of two target stations

The ISOLDE target and ion-source system

Target unit for selective production of He, Ne, Ar, Kr, Xe and Rn beams

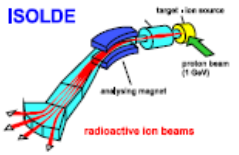


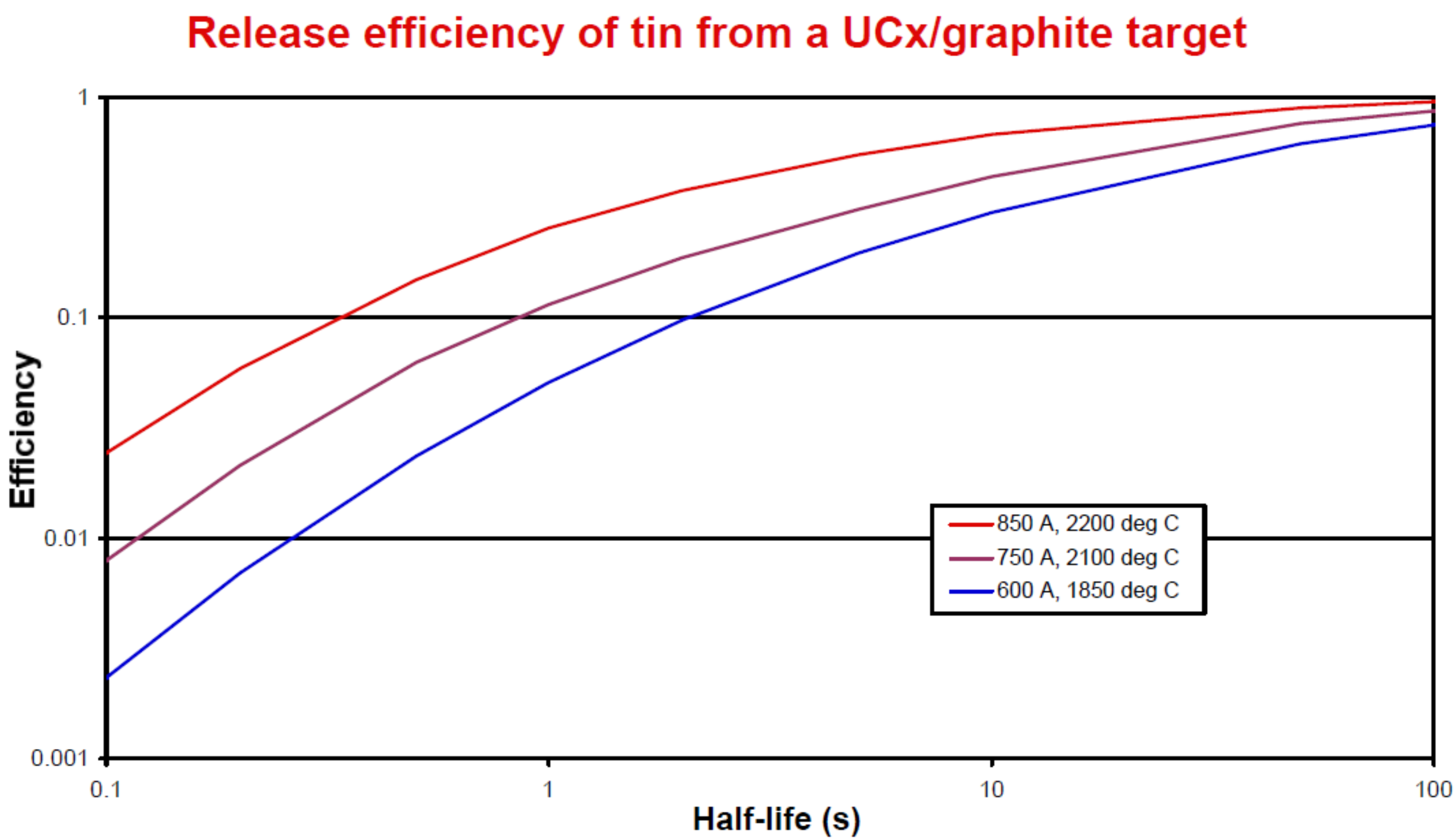
Separate systems developed for each element or group of elements

Liquid metal target materials used:

Thorium alloys
Lanthanum
Lead
Tin

EURISOL Release efficiency ε_1 ε_2 determined by the decay losses





Ref. Ulli Köster

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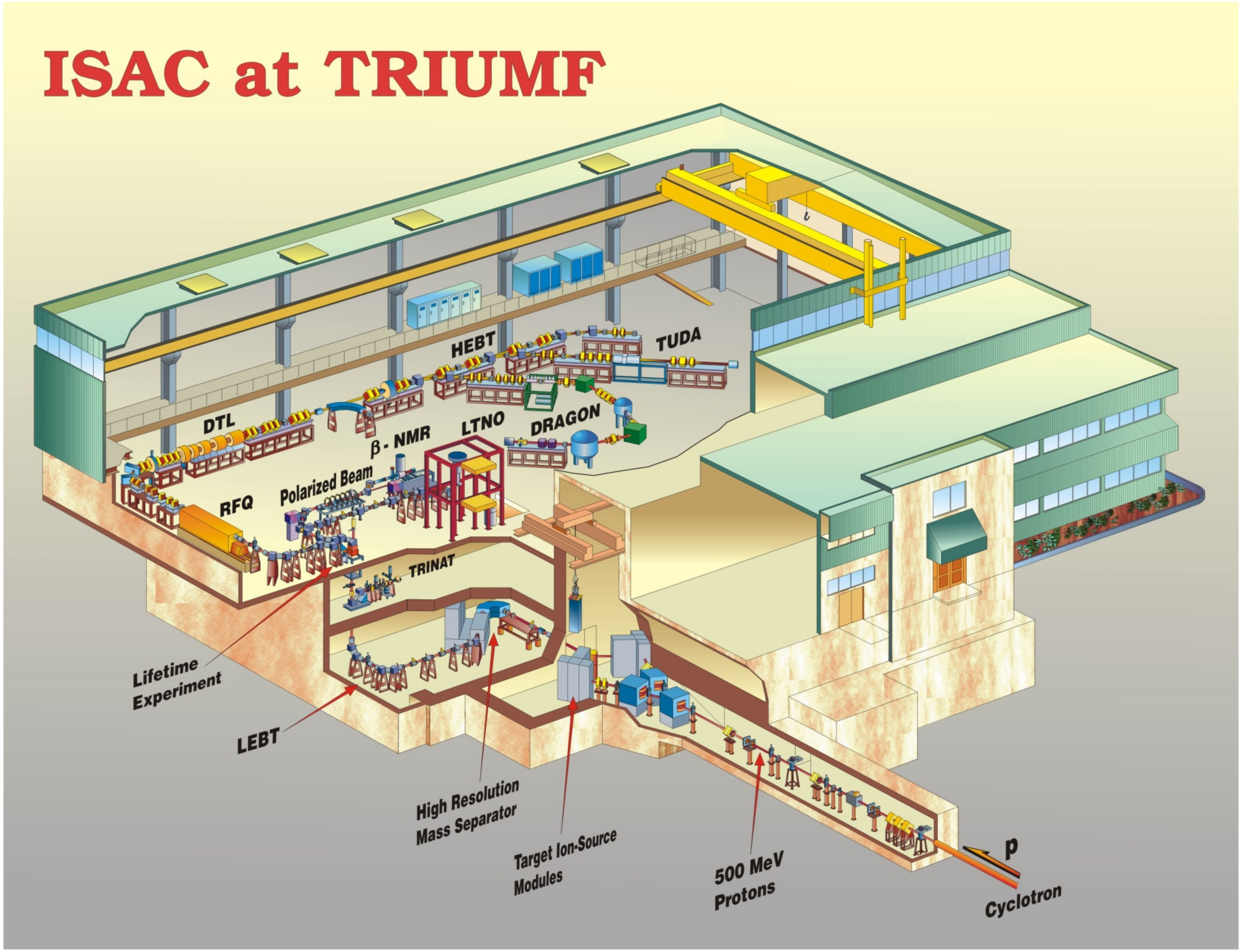
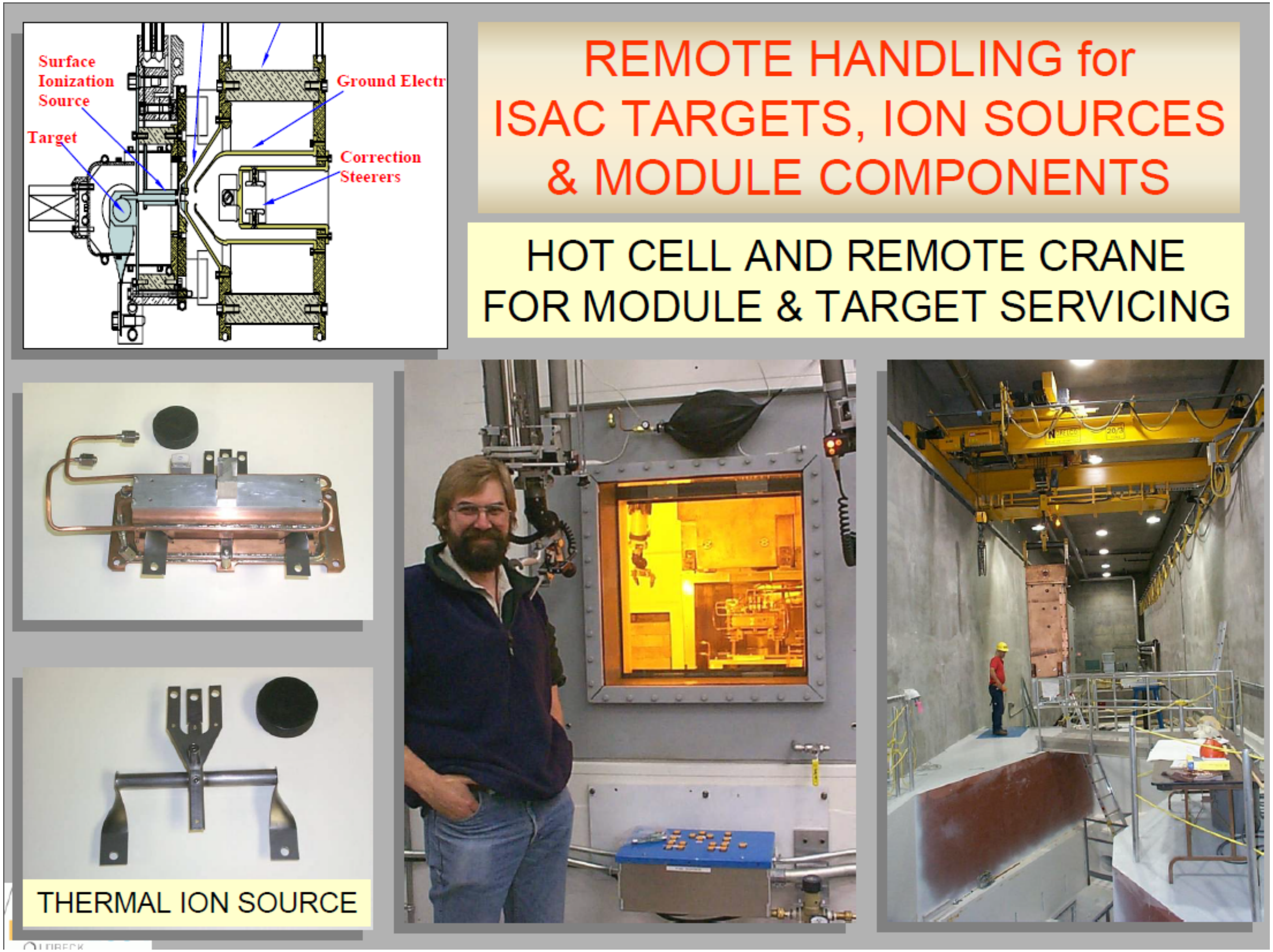
ISOL facility, ISAC @ TRIUMF: 500-MeV p, 100 μA



500-kW thorium target concept

High current density targets: 100 µA, 6-mm diameter

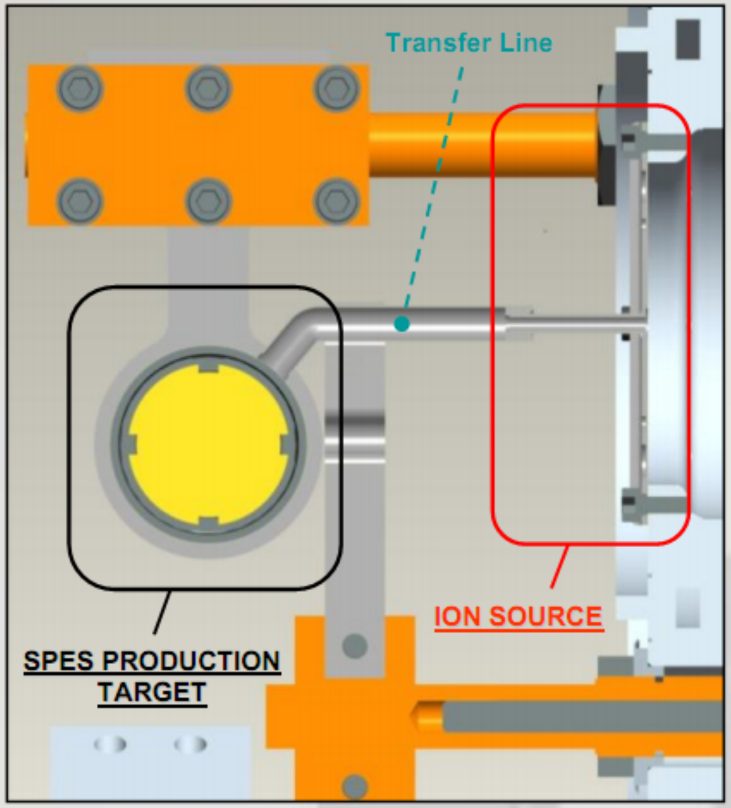


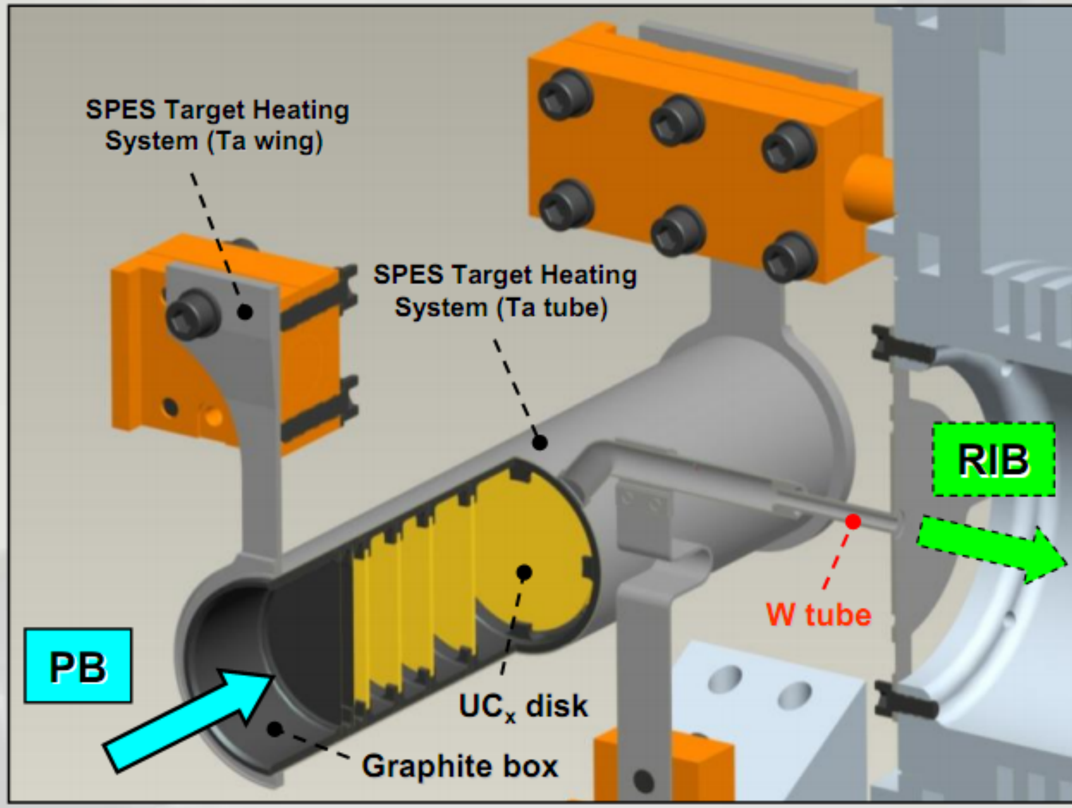
500-kW thorium target concept

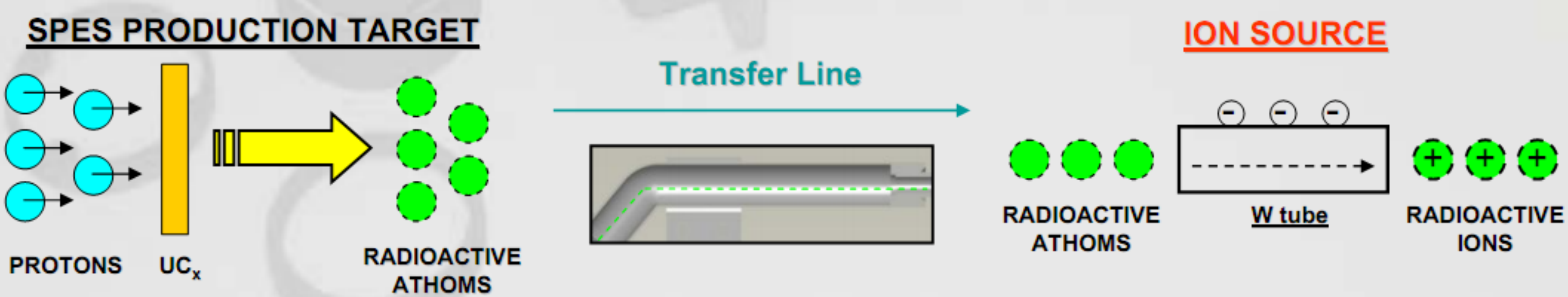
UC2 target designed at INFN Legnaro

- UC2 target for 40 MeV p, 400 microamps
  - 14 microamps/cm2
  - Higher dE/dx at lower energy
  - Detailed thermal simulations: thermal conductivity, thermal stresses, thermal radiation
  - Prototype tested for isotope release at Oak Ridge HRIBF
- Good starting point for extrapolation to Project X

Production zone: target and ion source







Extrapolation to 1-GeV, 500 μA for Project X: Rn, Fr, Ra

- Operating temperature ~2000 C to release isotopes
- Must radiate ~120 W/cm2 at this T
- Energy loss ~1500 W/cm -> diameter ~25 cm
- Optimum thickness ~200 g/cm2 thorium (~1 radiation length
- Average density ~2.5 g/cm3 (1-mm thick disks 5 g/cm2 with 1-mm spacing) -> target length ~80 cm, 400 disks
- Annular target, 1-cm diameter beam spot at ~12-cm radius; rotation > 1 kHz
- Insulation by 1 tungsten heat shield and 5-mm graphite felt
- Water cooling on outside surface

500-kW thorium target concept

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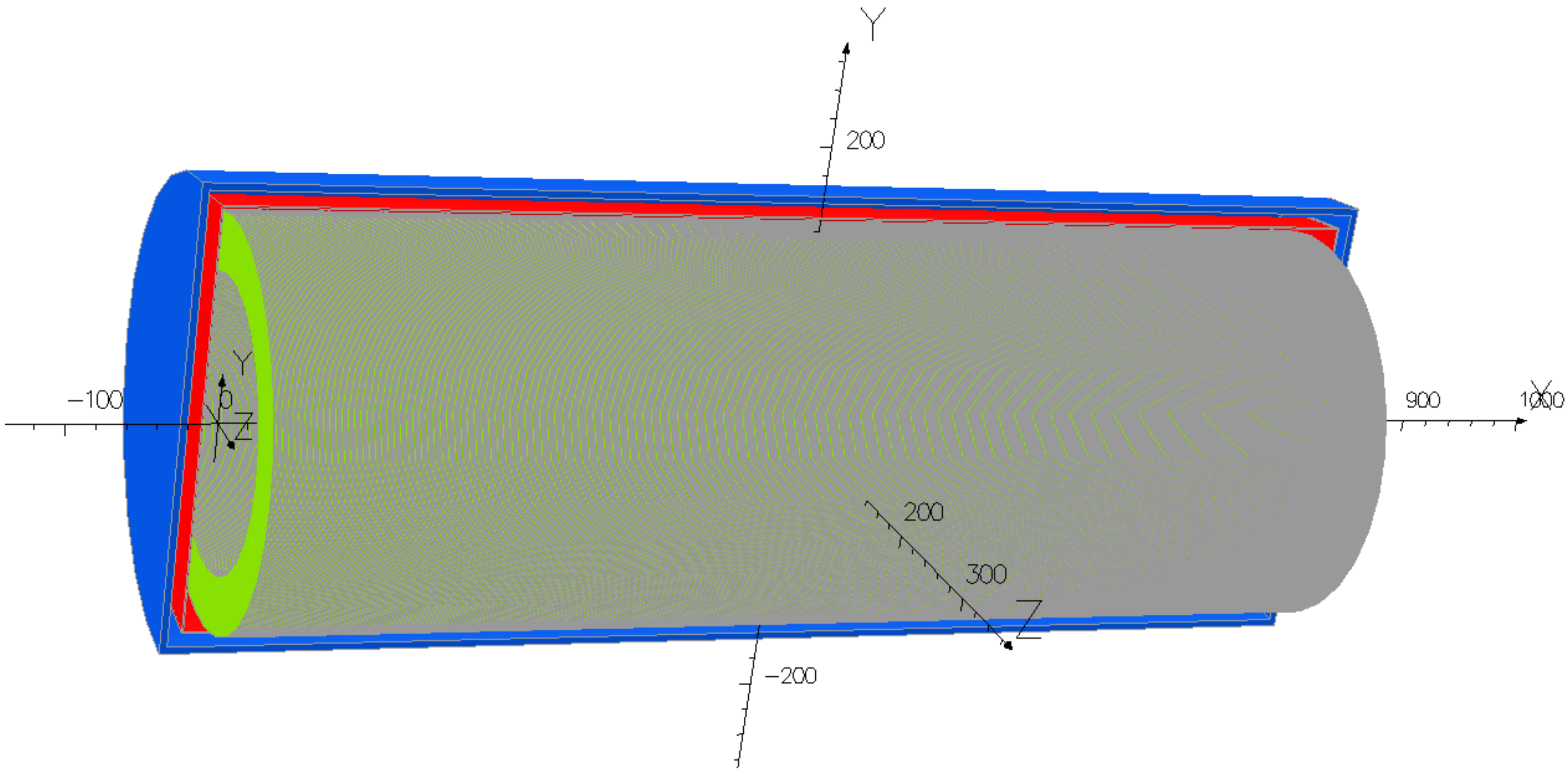
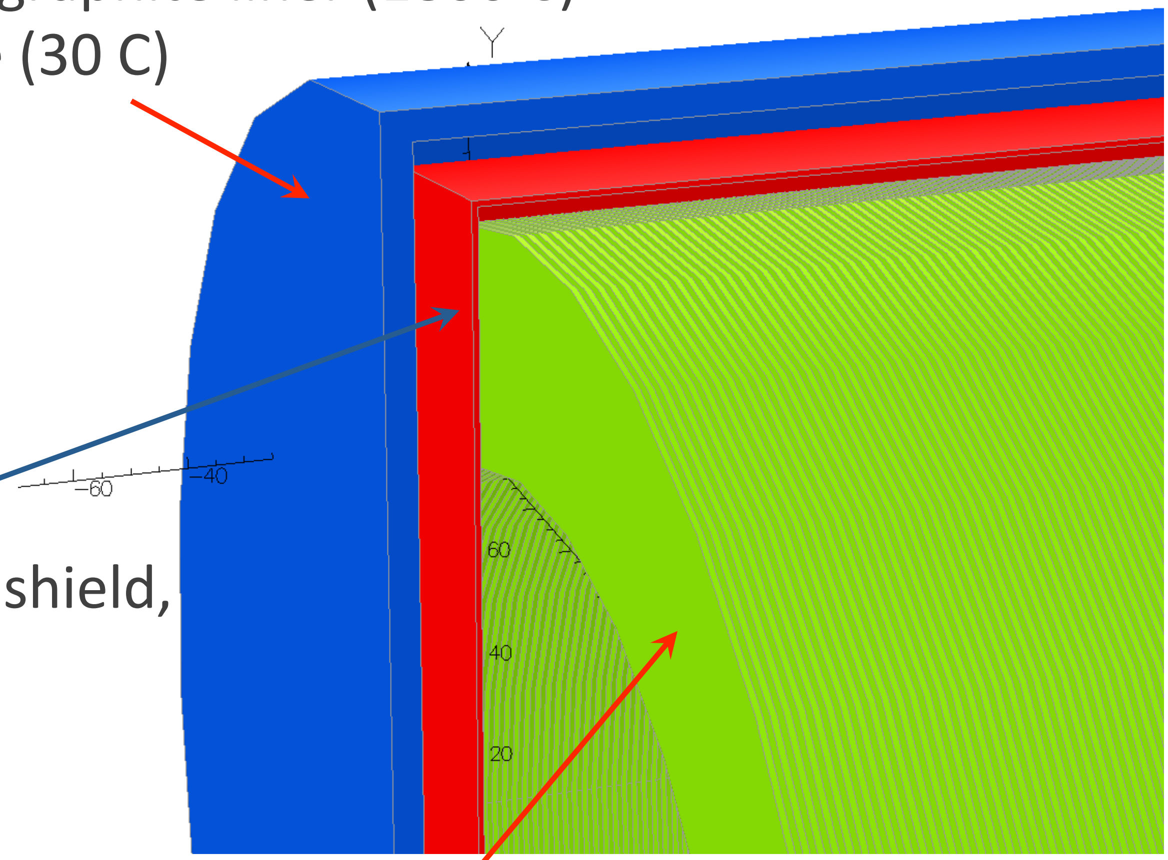


500-kW thorium target concept - close-up

Carbon felt insulation w/ graphite liner (1800 C) and water-cooled outside (30 C)



Tungsten container, heat shield, 2200 C

1-mm thick Th rings @ 1-mm spacing, 400 total, 2000 C

Isotope yields at PXIE

- At the Project X Injector Experiment (PXIE) with proton beams at 40 MeV/1 mA very useful yields of some isotopes will be available for physics research and instrument development
- A Legnaro-type UC target at PXIE can yield 5E13 fissions/s for n-rich isotopes
  - Extrapolation from 0.2 mA to 1 mA
  - Development relevant for extrapolation to 500 kW for Project X
- Large yields of heavy isotopes via (p,xn) reactions of Th and U targets will be available, e.g. Protactinium and Neptunium and others
  - What isotopes may be of interest for fundamental measurments?

500-kW thorium target concept

Monte Carlo simulations of effusion – model in Geant-4

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Optimization of ISOL targets based on Monte-Carlo simulations of ion release curves

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Abstract

A detailed model for simulating release curves from ISOL targets has been developed. The full 3D geometry is implemented using Geant-4. Produced particles are followed individually from production to release. The delay time is computed event by event. All processes involved: diffusion, effusion and decay are included to obtain the overall release curve. By fitting to the experimental data, important parameters of the release process (diffusion coefficient, sticking time, . . .) are extracted. They can be used to improve the efficiency of existing targets and design new ones more suitable to produce beams of rare isotopes.

500-kW thorium target concept

Monte Carlo simulations of effusion - model in Geant-4

Simulation of the Rutherford Lab "RIST" ISOL target design

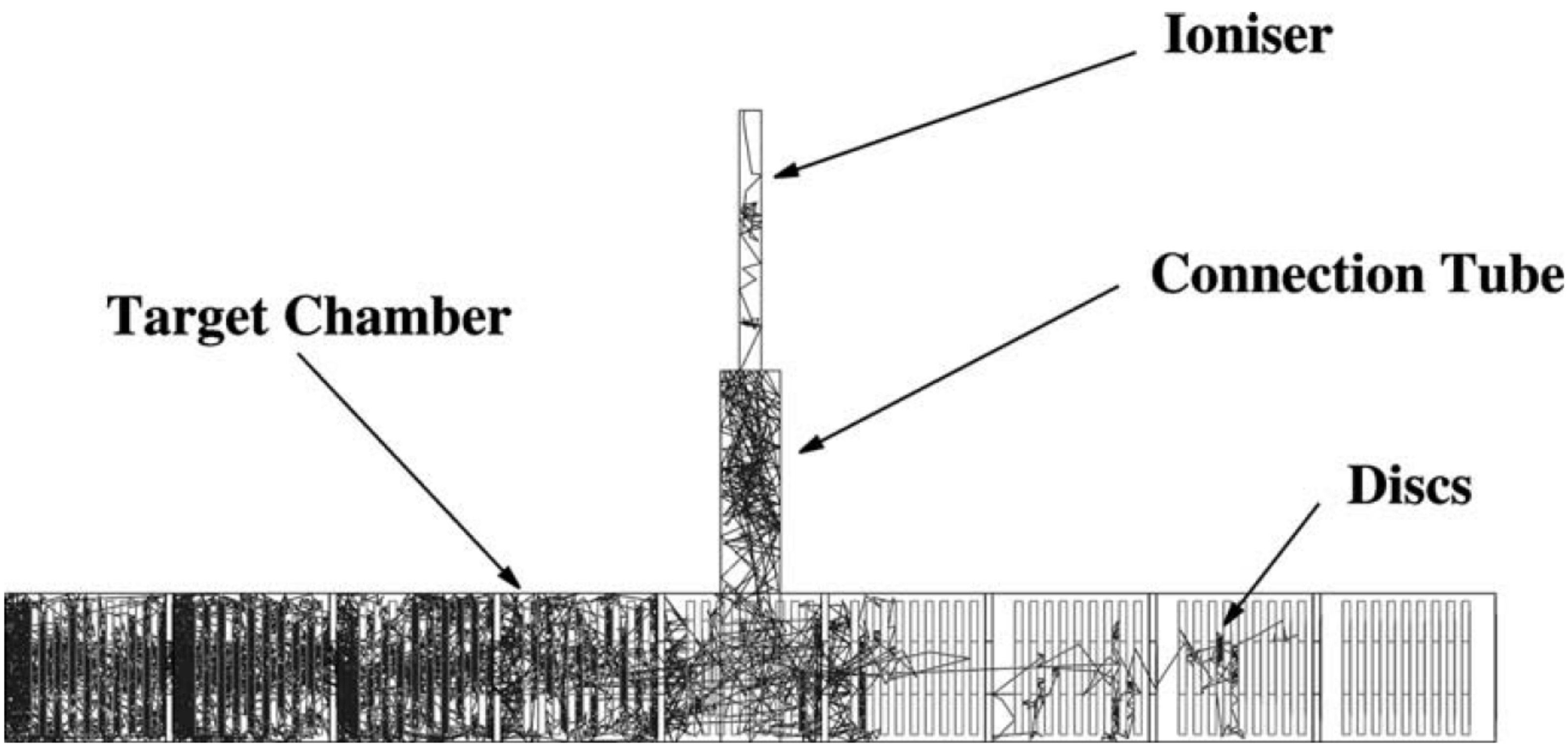

Fig. 1. Geometry of the RIST target showing the path of one particle from production to release.

Summary

- Parameters of existing ISOL spallation targets (CERN/ISOLDE, TRIUMF/ISAC, Oak Ridge HRIBF, Legnaro INFN/SPES) can be extrapolated to much higher beam power at Project X
- Issues to address
  - Effusion delays from large target chamber (Monte Carlo simulations)
  - Thermal conductivities and temperature limits of refractory thorium compounds: ThC_2, ThO_2, ThN
  - Thermal simulations coupling beam power deposition with thermal conduction, radiation, and stress effects
- Need to look at isotope production at PXIE for potential fundamental physics research

500-kW thorium target concept